Biomechanical Assessment and Neuromuscular Training to Mitigate Risk of Reinjury After ACLR

Laura Thornton,* PT, DPT, OCS, FAAOMPT, J. Brett Goodloe,*† MD, Inga Groseclose,* PT, DPT, Kevin Cross,* PhD, PT, ATC, and David R. Diduch,* MD
Investigation performed at the University of Virginia, Charlottesville, Virginia, USA

Background: Reinjury rates following anterior cruciate ligament (ACL) reconstruction remain high, and the cause is often multifactorial. There is growing literature supporting asymmetric biomechanical deficits leading to increased risk of reinjury. Neuromuscular training during postoperative rehabilitation may mitigate risk of reinjury by addressing these biomechanical deficits.

Indications: Neuromuscular training is supported in the literature to reduce primary ACL injury risk and modify biomechanical risk factors. Incorporating neuromuscular training into postoperative rehabilitation following ACL reconstruction may reduce the risk of reinjury.

Technique Description: The Landing Error Scoring System, or LESS test, is an assessment tool utilized to detect biomechanical asymmetries following ACL reconstruction. Video analysis allows for observation of subtle biomechanical differences. Neuromuscular training programs help improve these deficits through stepwise gradual and individualized progressions that are specific to each patient's needs and desired athletic return.

Results: A patient who participates in neuromuscular training as a component of postoperative rehabilitation should demonstrate improvements in their individual biomechanical deficits at the completion of the program described.

Discussion/Conclusion: Biomechanical assessment following ACL reconstruction, such as the LESS test, can identify deficits that may increase risk of reinjury. Neuromuscular training following ACL reconstruction can address these deficits and potentially mitigate risk of reinjury.

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Keywords: ACL injury; neuromuscular training; secondary ACL injury; asymmetry; biomechanical deficit; injury risk reduction; rehabilitation

VIDEO TRANSCRIPT

Biomechanical Assessment and Neuromuscular Training to Mitigate Risk of Reinjury After ACL Reconstruction, Department of Physical Therapy and Orthopedic Surgery at the University of Virginia.

The senior author's disclosures are listed here.

Our objectives of this presentation were to summarize evidence behind biomechanical measures and risk factors found after ACL reconstruction (ACLR), to demonstrate the Landing Error Scoring System (LESS) test as a clinical assessment of these biomechanical measures, define neuromuscular training and review the current evidence, and demonstrate a progression through a neuromuscular training program.

High incidence rates of primary ACL injury per 1000 athlete exposures reported here are from a 2021 systematic review of adolescent athletes across different high school sports.[1] Our focus today however is on the second ACL injury, either rupture of the graft or ACL injury to the

†Address correspondence to J. Brett Goodloe, MD, Department of Physical Therapy and Department of Orthopaedic Surgery, University of Virginia, 2280 Ivy Road, Charlottesville, VA 22903, USA (email: jg4xd@uvahealth.org).

*Department of Physical Therapy and Department of Orthopedic Surgery, University of Virginia, Charlottesville, Virginia, USA.

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contralateral limb. A systematic review in 2016 reported secondary injury rates of 21%.[2] Wide ranges of this statistic have been reported with a majority of studies reporting somewhere in between 10% and 30%. The risk factors remain multidimensional; however, today, we are going to focus on the biomechanical risk factors.

Asymmetry found on biomechanical assessments after ACL injury may be a potential risk factor for a second ACL injury. The strongest support of asymmetry after ACLR has been found using a double-limb landing task in the sagittal plane. Two systematic reviews found in agreement that reduced knee joint moments and ground reaction forces are common on the injured side, indicating knee stiffness while landing and joint offloading onto the uninjured side.[3,4] This assessment can be performed reliably in a clinic, through functional testing.[5]

Two individual studies are worth noting looking biomechanical risk factors found after ACLR. In a study by Paterno and his colleagues from 2010, athletes who had undergone ACLR were followed up for 12 months after functional testing and the following biomechanical risk factors were correlated with a secondary injury: decreased extension moment; increased lateral trunk flexion, increased knee valgus displacement, and increased hip internal rotation moment on the uninjured side.

When combined, these findings could predict the reinjury group with a high sensitivity and specificity rate. In addition, hip internal rotation on the uninjured side alone was also a powerful predictor of those that were reinjured.[6] In 2021, King and his colleagues investigated a cohort of male athletes for 2 years. Findings of a lower center of mass, increased knee flexion, and increased ground contact time on the injured side predicted reinjury with a moderate sensitivity and specificity rate.[7] We likely see an influence of gender in these 2 studies.

The LESS test has been found to be a reliable and valid biomechanical assessment tool to observe whether an athlete demonstrates any of these previously mentioned risk factors in a jump landing task. This can be done in a clinical setting easily. The participant jumps down from a 30-cm box to a distance that is one half their height from the box and then immediately after landing, jumps vertically as high as possible.

The score is a count of landing technique "errors" on 17 different observable items, with a maximum score of 19. A lower score is better, and less than 5 is established most commonly as a passing score. The items of interest pulled from the previously mentioned studies are circled: knee flexion angle at initial contact, knee valgus at initial contact, lateral trunk flexion at contact, and joint displacement in the sagittal plane or stiff landing.

These are side-by-side videos where you can see biomechanical asymmetries in the sagittal plane. Note the stiffer landing on the left with a reduction in knee flexion angle at initial contact.

This is the same jump from a frontal plane view, noting the left knee valgus displacement and lateral trunk flexion at initial contact.

These images are paired frames from the previous videos. The top left shows differences in knee flexion at initial contact. The bottom left shows a stiff versus a nonstiff landing. The top right shows knee valgus during landing, and the bottom right shows lateral trunk flexion during landing.

We are going to now shift to show you a 4-phase progression through a neuromuscular training program. Please note, neuromuscular training is not just going through a set of predetermined drills. It starts with fundamental movement retraining, progressing through more challenging variables, shifting focus of attention, and progressing to unpredictable and fast changing sport like environments. To complete this process, the athlete must maintain proper biomechanics through all the different phases.

In phase 1, we break down fundamental movements and retrain proper mechanics during these movements. We teach the athlete the important components and to ensure the athlete learns at their optimal level, we utilize different forms of feedback such as mirror feedback, tactile feedback, externally focused feedback, and laser control. We also add in resistance to the movement pattern by adding weight or adding acceleration and deceleration drills to ensure stronger defense against those poor biomechanics. We stay at this step until the athlete can demonstrate proper form without need for additional cueing.

Progressing to phase 2, we will challenge the athlete through different variables but maintain the athlete's focus on their proper biomechanics during the movement. We do this through adding different speeds, say with metronome training, or adding in different changes of direction, or increases in amplitude of the movement to enhance the athlete's learning. Again to reiterate, the athlete still has their focus and attention on their own biomechanics and form during this phase.

One of the most important concepts of neuromuscular training is in the transition between phases 2 and 3. In phase 3, the athlete will now shift their attention to an external object instead of their own form. This will ensure that the athlete adapts a previously conscious effort into now an automatic movement pattern. While the athlete is focused on the external object, we challenge this through balance tasks with perturbations, ball catching and tossing during either landing drills or lateral acceleration and deceleration drills such as on a slide board, random targets tapping with their hand or their foot, or even guarding the athlete during a challenging sport-specific movement, such as pivot turns.

Phase 4 is the final phase where we increase the dynamic component of the neuromuscular training and make the task as sport specific as possible. The athlete will still focus on the external object, as they would in their individual sport; however, we will now add an unpredictable environment to adapt to. We are still monitoring the form and ensuring carryover of all the previous phases of learning.

To assist with determining readiness for return to play, we at the University of Virginia use the Lightweight Extensible Authentication Protocol, which utilizes 4 different domains of function, including the LESS test mentioned earlier. The neuromuscular training framework targets the categories of Return to Play criteria focused on both patient-reported function and biomechanics.

The majority of studies investigating neuromuscular training have been focused on preventing primary ACL injury.[8] However, there are only a few studies directly investigating how neuromuscular training might mitigate a second ACL injury. Two studies are worth highlighting that neuromuscular training was found to reduce those biomechanical risk factors that we mentioned earlier for both healthy cohorts and patients post-ACLR as seen here.[9,10] Based on the success of primary injury prevention and the reduction in biomechanical risk factors, we may infer that neuromuscular training could have an influence on second ACL injury and suggest that rehabilitation programs should incorporate this type of training.

Neuromuscular training is a progressive, individualized process that should be an integral part of ACLR rehabilitation. It is not 1 specific drill, but a systematic framework of learning, retention, and transfer based on the individual biomechanical assessments. The key components of these programs should include monitored progressions to ensure the athlete carries over learning from phase to phase. It should include the shift from internal attention to external attention which has been found to result in greater efficiency of movement and frees up the athlete's ability to shift their cognitive focus from their own body to the task at hand. Augmented feedback can also enhance the athlete's learning and skill transfer and has been shown to reduce high-risk injury landing mechanics.[11,12]

Finally, there is an inverse dose–response relationship between neuromuscular training volume and injury risk rate. So, multiple sessions over a longer duration show an increased benefit over a shorter duration of training.[13] This of course is not the sole component of a comprehensive rehab program. Neuromuscular training should be combined with several other components to tailor to the individual athlete, whatever their needs may be.

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These are our references.

Thank you for your time.

ORCID iDs

J. Brett Goodloe https://orcid.org/0000-0002-4144-6856
Kevin Cross https://orcid.org/0000-0002-3245-8791

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